Anaesth Crit Care Pain Med 45 (2026) 101621

Contents lists available at ScienceDirect

Anaesthesia Critical Care & Pain Medicine

journal homepage: www.elsevier.com

Review article

Intravenous magnesium administration errors, attributing factors and associated respiratory or cardiopulmonary arrest in obstetric and non-obstetric patients—A systematic review

Santosh Patel [a,b,*]

[a] Department of Anaesthesia, Tawam Hospital, Al Ain, United Arab Emirates
[b] Department of Clinical Sciences, Gulf Medical University, Ajman, United Arab Emirates

ARTICLE INFO

Article history:
Available online 29 September 2025

Keywords:
Magnesium sulphate
Intravenous, administration
Medication error
Obstetrics
Cardiopulmonary arrest
Cardiac arrest

ABSTRACT

Background: The primary objective of this systematic review was to investigate intravenous (IV) magnesium administration errors and associated adverse outcomes in hospital settings. The secondary objective was to identify contributory factors using the human factors and analysis classification system (HFACS) framework.
Methods: PubMed, Scopus and Google Scholar were searched using the systematic search protocol for the past five decades. Magnesium administration errors were included, provided the route of administration was IV, and the clinical outcomes were described. Reports of errors *via* other routes were excluded.
Results: The search identified 32 reports (31 obstetric and 15 non-obstetric patients). Errors occurred in wide-ranging locations. Most errors (36 of 46) occurred during maintenance dose infusion. For obstetric patients, errors occurred in patients with preeclampsia (n = 24) or preterm labour (n = 7) during varying periods of pregnancy. In four women, perimortem (2 patients) or within a few hours of cardiopulmonary resuscitation, lower segment caesarean sections were performed. Nearly two-thirds (63%) of patients developed either respiratory arrest only (9 obstetrics and four non-obstetric) or cardiopulmonary arrest (10 obstetrics and six non-obstetric). The permanent harm occurred in six patients (death −3 and vegetative state −3). Most contributory factors were skill-based errors, adverse mental state, communication and coordination of care, and deficiencies in magnesium-related processes.
Conclusions: The findings highlight the need for improved IV magnesium administration practices across wards and acute care settings. Standardisation of magnesium products, their labelling, preparation, as well as reliable monitoring processes during the therapeutic use of magnesium, are essential to prevent magnesium infusion errors.
© 2025 Société Française d'Anesthésie et de Réanimation (SFAR). Published by Elsevier Masson SAS. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

Introduction

Intravenous (IV) medication administration is a common practice in hospital settings for medical, surgical, and obstetric patients. Many of these patients are in critical condition, requiring urgent intravenous medication administration while doing other clinical tasks. The administration of IV medication requires multiple procedural steps (*e.g.*, prescribing, picking up, preparing, administering, and monitoring) to ensure the safe execution of the complete task and avoid associated adverse outcomes. IV route medication errors are common, particularly in administration type, and may lead to severe morbidity and mortality [1]. The practices of preparation and administration of IV medications are variable and vulnerable to human and systemic deficiencies [2].

Furthermore, supportive physical and technological facilities, such as storage, admixing, infusion pumps, monitoring, and documentation, may also influence patient safety during the IV administration of medications [3]. These processes can be further complicated and may increase the risk of mishaps when the modes of administration are combined (*e.g.*, bolus followed by infusion). For example, one study showed that errors and discrepancies are

* Corresponding author at: Department of Clinical Sciences, Gulf Medical University, Ajman, United Arab Emirates.
E-mail address: skpatel@seha.ae">SantoshPatel[ab*]skpatel@seha.ae.

https://doi.org/10.1016/j.accpm.2025.101621
2352-5568/© 2025 Société Française d'Anesthésie et de Réanimation (SFAR). Published by Elsevier Masson SAS. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

relatively common in everyday infusion administrations, but most have a low potential for patient harm [4]. Moreover, IV medication use is a collaborative effort involving multiple professionals, including doctors, nurses, midwives, and pharmacists, who provide services in various locations, such as wards, operating rooms (OR), emergency departments (ED), and critical care units. Each professional's role is crucial in ensuring the safe administration of IV medication.

High-alert medications, a category that includes drugs associated with a heightened risk of causing significant patient harm when an error occurs, demand utmost vigilance and adherence to safety protocols. Although there is no data on the frequency of mistakes with these drugs, the consequences of an error are more likely to be devastating to patients [5]. Magnesium, a high-alert medication, is indicated in many clinical conditions. For example, therapeutic use of IV magnesium in the adult population for acute problems in obstetric, respiratory, cardiovascular, anaesthesia, pain, and neurology specialities [6–10]. Another indication is correcting hypomagnesemia in acute care settings, such as intensive care units (ICUs), emergency departments (EDs), and operating rooms (ORs). Accordingly, magnesium ampoules, vials, and premixed infusion bags are stored along with other medications and IV fluids in the wards, including labour and busy clinical care locations. Depending on the local hospital policy, the care provider may prepare a magnesium bolus or maintenance infusion at the point of administration. Patients may require a transfer from one acute location to the routine ward or *vice versa* (*e.g.*, from the emergency department to the antenatal ward or from the delivery suite to the operating room) while an IV magnesium infusion is ongoing.

The fact that magnesium sulphate (MgSO4, now also referred to as magnesium) is available in ampules or vials containing a wide range of concentrations creates significant risks for medication errors, predisposing not only to mix-ups with other medications but also to the selection of the appropriate magnesium vial, ampule, or infusion bag. A comprehensive review of IV magnesium administration errors is lacking in the literature. Therefore, the current study aimed to identify the clinical characteristics, potential severity, and outcomes of IV magnesium administration errors. The secondary objective was to identify systemic and human contributory factors and possible areas of improvement to prevent.

Methods

The author systematically searched PubMed, Scopus, and Google Scholar for published reports of intravenous magnesium errors in humans from 1976 to January 2025. There was no language or restriction applied. For PubMed, a combination of MeSH term and keywords were used to formulate a search query: (("intravenous" [TIAB] OR "IV" [TIAB] OR "infusion" [TIAB] OR "overdose" [TIAB] OR "life-threatening" [TIAB] OR "toxicity" [TIAB] OR "therapy" [TIAB] OR "administration" [TIAB]) AND ("accidental" [TIAB] OR "iatrogenic" [TIAB] OR "inadvertent" [TIAB] OR "medication error" [TIAB] OR "apnoea" [TIAB] OR "arrest" [TIAB] OR "respiratory" [TIAB] OR "ventilation" [TIAB] OR "cardiopulmonary" [TIAB] OR "resuscitation" [TIAB] OR "harm" [TIAB] OR "lethal" [TIAB] OR "hazards" [TIAB]) AND ("magnesium" [TIAB] OR "magnesium sulphate" [TIAB] OR "hypermagnesemia" [TIAB] OR "hypermagnesaemia" [TIAB] OR "hypomagnesaemia" [TIAB] OR "hypomagnesemia" [TIAB] OR "MgSo4" [TIAB])). The detailed database search strategy is described in Supplemental File 1. For Google Scholar, articles were also searched using ‘‘related articles" and "cited by" links. We manually searched references from the eligible articles to identify additional magnesium error reports. We included all language articles. The PRISMA checklist is included in the Supplemental File 2.

The author included publications that reported one or multiple errors during the therapeutic use of magnesium, provided the route of administration was intravenous (IV), and the report described the final clinical outcome. The author included error reports that described mishaps during loading dose (bolus) and infusion (from the start or following a loading dose) administration errors in any hospital location (*e.g.*, wards, acute care areas). The author excluded reports of errors *via* other routes than the IV route (*e.g.*, oral, intrathecal, epidural). IV magnesium side effects or toxicity due to the exaggerated effects of magnesium in the presence of specific medical problems (*e.g.*, renal failure, neuromuscular disorders) were excluded. The author also excluded reports where iatrogenic hypermagnesemia was suspected, but the potential cause was not clear.

The author categorised the population involved into obstetric and non-obstetric groups. For each of these two groups of patients, age, indication for magnesium use, clinical location, mode of administration (bolus or infusion), and the dose of administration were recorded in a standardised format. When an error occurred in one place but was detected in another or when magnesium was administered safely in one location but subsequently occurred in another following patient transfer, both locations were recorded. We documented clinical circumstances, clinical features, investigations, and consequences of magnesium administration errors. We also recorded other medical conditions considered during differential diagnosis, as described in the reports.

For adverse outcome analysis, the author focused on serious sequelae in the form of life-threatening (defined as if the event causes systemic features that, if not treated, would result in death), respiratory arrest, or cardiopulmonary arrest. The permanent adverse outcomes were classified as death or vegetative state requiring life-long dependent care.

Finally, the author applied the human factors analysis classification system (HFACS), based on James Reason's Swiss cheese model, to classify contributing factors into four main categories, each further classified into a variable number of subcategories. The three categories include latent deficiencies (organisational issues, unsafe supervision, preconditions for unsafe acts), and the last is active failures categorised as unsafe acts. Each main category has several subcategories to include a wide range of potential factors present before or during the incidents. Analysis of the incident characteristics and HFACS data was performed using frequency counts.

Results

As shown in the PRISMA flow chart, 46 patients are included for analysis (Fig. 1). There were 31 obstetric [11–31] and 15 non-obstetric patients [32–42]. In non-obstetric patients, 4 of 15 patients were paediatric (including two premature and two infants) [37–39], and four were geriatric (age $\geq$ 65 years) [32,34,35,41]. Some reports contained more than one incident [24,31,32,36,37].

Table 1 summarises the indication for magnesium therapy, location of incidents, mode of therapy when the error occurred (during loading or maintenance dose infusion), and

outcome for obstetric and non-obstetric patients. For obstetric patients, diagnosis at the time of error, pregnancy stage, and its outcome are included in Table 2. Supplemental File 3 (Table) summarises the individual patient's clinical features, main investigations, highest reported magnesium level, management, and outcome for non-obstetric patients.

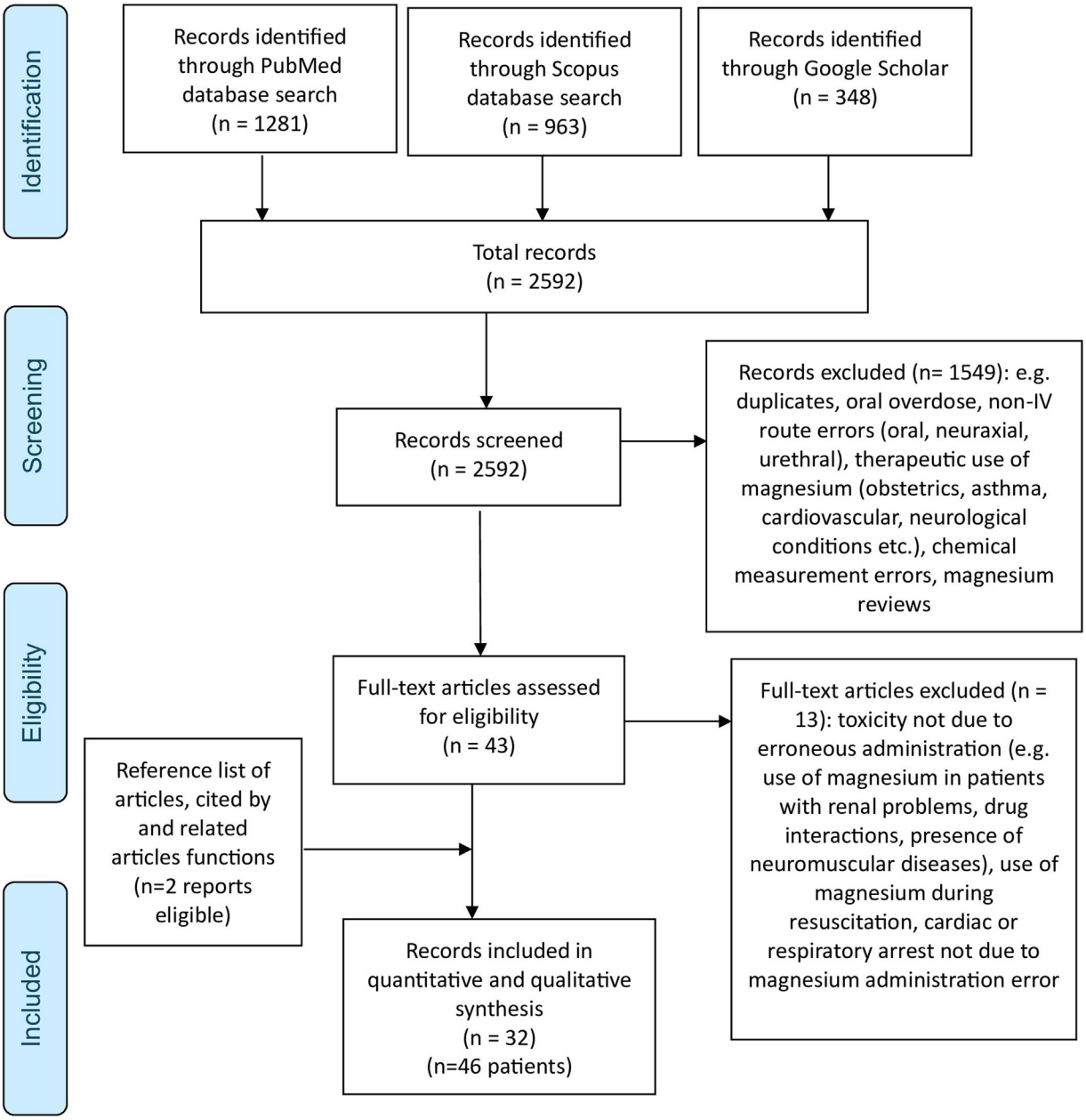
Identification
Records identified through PubMed database search (n = 1281)
Records identified through Scopus database search (n = 963)
Records identified through Google Scholar (n = 348)
Total records (n = 2592)
Screening
Records screened (n = 2592)
Records excluded (n= 1549): e.g. duplicates, oral overdose, non-IV route errors (oral, neuraxial, urethral), therapeutic use of magnesium (obstetrics, asthma, cardiovascular, neurological conditions etc.), chemical measurement errors, magnesium reviews
Eligibility
Full-text articles assessed for eligibility (n = 43)
Full-text articles excluded (n = 13): toxicity not due to erroneous administration (e.g. use of magnesium in patients with renal problems, drug interactions, presence of neuromuscular diseases), use of magnesium during resuscitation, cardiac or respiratory arrest not due to magnesium administration error
Reference list of articles, cited by and related articles functions (n=2 reports eligible)
Included
Records included in quantitative and qualitative synthesis (n = 32) (n=46 patients)

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram for the intravenous magnesium administration incidents. In this figure, records excluded number should be read as 2549 in place of 1549.

Indication

Obstetric

Magnesium was administered either for preeclampsia (n = 24 of 31, 77.4 %) [11–14,6–17,19–26,28–31] or preterm labour (n = 7 of 31, 22.6%%) [15,18,27,31] (Table 1). Among women with preeclampsia, the severity, dose of magnesium administered, protocol for magnesium bolus and infusion administration, and monitoring were variable. In patients with preterm labour, magnesium was used predominantly as a tocolytic agent [15,18,27,31].

Non-obstetric

The predominant indication was hypomagnesemia associated with a variety of critical illnesses [32–34,36,38,39,41]

Location

The incidents occurred in routine wards (maternity, medical, surgical, oncology, and paediatric) and acute care areas, such as the labour ward, ED.

Obstetrics

Two locations involved nearly one-third (10 of 31) of obstetric errors [17,19–21,24,30,31]. For example, the error occurred in one area but was not detected until after the patient was transferred to another location (*e.g.*, from the ED to the maternity wards or ICU). For some patients, magnesium was safely administered at one location. Still, errors occurred during transfer (*e.g.*, from the recovery room to the postnatal ward [17], from the ED to the

Table 1
Indication, Locations, Mode of therapy, Differential diagnosis and Outcome associated with IV magnesium administration errors.

	Obstetric (n = 31 patients)	Non obstetric (n = 15 patients)
Indications	• Preeclampsia: 24 [11–14,16,17,19–26,28–31] • Preterm labor: 7 [15,18,27,31]	• Hypomagnesemia: 8 [32,34,36,38,39,41] • Cardiac: 1 atrial fibrillation and 1 suspected acute myocardial infarction [32,35] • Erroneous preparations of total parental nutrition: 2 [37] • Incorrect infusion bag (in place of potassium chloride): 1 [40] • Not clear: 2
Location	• Two locations (occurrence and detection different locations including involving intrahospital and interhospital transfers): 10 [17,19–21,24,30,31] • Maternity wards (Delivery suite/labour ward, antenatal or postnatal ward): 8 [15,16,26,27,31]: • OR: 4 [21,23,24,29] • ED: 4 [18,24,28,31] • Unclear/Not mentioned: 5	• Wards (medical/surgical/hemato-oncology/neonatal): 8 [32,38,39,41,42] • ED: 5 [32,35,36,40] • ICU: 1 [33] • Two locations (occurrence and detection different locations): 1 • Unclear/Not mentioned: 1
Bolus or Infusion	• Bolus (loading dose administration): 10 [11,12,14,19,24,27,28,31] • Maintenance dose infusion: 21 [11,13,15–18,20–23,25,29,31]	• All infusions (without loading dose): 15 [31–42]
Considered differential diagnosis during iatrogenic hypermagnaesemia	• Intra-cranial aneurysm, Metabolic, Eclampsia [11] • Suxamethonium apnea [23] • Delayed recovery [25] • Pulmonary embolism, amniotic fluid embolus, cerebral edema, maternal stroke or seizure [26] • Epilepsy, cerebral haemorrhagic event, metabolic or toxic encephalopathy, and ischemic stroke [28] • Hypoxic-ischemic encephalopathy [29]	• Central brain-stem syndrome as a rare complication secondary to cerebral edema [33] • Septic shock syndrome [37] • Stroke, Seizures, Cerebral metastases (in the presence of cancer) [41] • Anaphylaxis [42]
Respiratory or Cardiac arrest	• Respiratory arrest]: 9 [13,15,17–19,26,29,31] • Cardiopulmonary arrest: 10 [11,12,14,16,20,22,27,28,31]	• Respiratory arrest: 4 [33,35,37] • Cardiopulmonary arrest: 6 [32,34,36,38,40]
Final Outcome	• Death: 2 [12,31] • Vegetative: 2 [31] • Survival: 27	• Death: 1 [36] • Vegetative: 1 (anoxic brain injury) [32] • Survival: 13

ED-emergency department, OR-operating room, ICU-intensive care unit.

maternity ward, OR, or ICU [19,27], and from the maternity ward to the OR [20]).

Non-obstetric

The highest number of medication errors occurred in the following departments in order: wards (n = 7), followed by ED (n = 5).

Mode of administration

Most administration errors occurred during the magnesium maintenance infusion in obstetric and non-obstetric patients. None of the mistakes was due to malfunctioning devices.

Obstetric

In 10 pregnant women, errors were reported during the bolus administration stage due to wide-ranging causes (*e.g.*, uncontrolled infusion, or miscommunication of prescription) [11,12,14,19,24,27,28,31].

Infusion

In 21 (of 31) patients, magnesium maintenance infusion incidents were attributed to wide-ranging causes [11,13,15–18,20–23,25,29,31]. For example, the magnesium administration set remained connected without the pump, leading to free flow during transfer, failure to disconnect the IV magnesium infusion set once it was no longer needed, assumption about the verbal order or prescribed dose, wrong calculation of the infusion rate, and inadequate monitoring during bolus or maintenance infusion therapy. In one obstetric case, an error occurred despite using a smart infusion pump because the nurse was unfamiliar with its functions.

Non-obstetric

The maintenance (without a loading dose) infusion was the initial mode of therapy for all patients [32–42]. In four paediatric patients [37–39], infusion complications occurred because 40 g of magnesium sulphate was administered in place of 4 g [38], ten times the recommended dose [39], and an automated total parenteral nutrition mixing device malfunctioned [37]. Most reports did not describe the type of infusion device or rate regulation [32–36,38,40,33–42].

Outcome

Obstetrics (Table 2)

Of 20 antenatal women who received erroneous magnesium, two underwent perimortem LSCS [22,28], one immediately after cardiac resuscitation in OR [20] or one [12] or 12 h after [11] cardiopulmonary resuscitation. The contributory factors in these

Table 2
Diagnosis, weeks and period of pregnancy and outcome following IV magnesium administration errors in 31 obstetric patients.

Reference	Weeks of pregnancy/Diagnosis	location	Pregnancy period during Mg error	comments
[11]	37/PET	Unclear	Antenatal	Cardiac arrest. 12 h. after the event LSCS.
[12]	FT/PET	Unclear	Antenatal	Cardiac arrest. LSCS 1 h. after the event. Death after 4 days.
[13]	27/PET	Ward	Postpartum-post LSCS	18 h post LSCS, when the patient was moved, the infusion set was disconnected from the infusion pump and not replaced.
[14]	32/Eclampsia	Unclear	Antenatal	Cardiac arrest. Post resuscitation pregnancy continued. LSCS at 36 weeks.
[15]	32/PTL (tocolytic)	Not mentioned	Antenatal	Few hrs after the incident spontaneous delivery of twins.
[16]	39/PET	Ward (labour)	Postpartum- shortly after ND	The infusion pump was disconnected
[17]	38/PET	Transfer	Postpartum-post LSCS	On arrival from recovery room.to postpartum ward.
[18]	26/PTL (tocolytic)	ED	Antenatal	Admixing problem. R/R – 5/ minute. Normal pregnancy continued.
[19]	Not reported Eclampsia	Transfer	Postpartum- 17 h after ND	On arrival in ICU, collapsed due to uncontrolled infusion during transfer
[20]	36/PET	Transfer	Antenatal	Immediate after cardiac arrest in the OR- LSCS performed after resuscitation.
[21]	33/PET	Transfer/OR	Antenatal	Unlabelled infusion bag continued in the OR. Error detected after baby delivery.
[22]	40/Eclampsia	Labour ward	Antenatal	Perimortem LSCS. Uncontrolled rapid infusion.
[23]	32/PET	OR	During LSCS after delivery of the baby	Instead of increasing the infusion rate of oxytocin the anaesthetist increased the magnesium infusion
[24] (two patients)	Not reported/ 1-PET, 2 Eclampsia	1-OR 2-Transfer	1-During LSCS 2- Antenatal (from ED to LR)	First case emergency under general anaesthesia. In both cases, infusion rate was not decreased following bolus dose administration.
[25]	36/PET	ED	Antenatal	LSCS within few hours of the error. Delayed recovery from anaesthesia.
[26]	Not reported/Severe PET	Ward (postnatal)	Postpartum (normal delivery of twins)	During management of PPH, uncontrolled magnesium administration in place of oxytocin.
[27]	27 / PTL	Ward (labour)	Antenatal	Several days after the event LSCS because of unrelated complications.
[28]	31/Eclampsia	ED	Antenatal	Perimortem LSCS.
[29]	Full term/PET	OR	Postpartum-post LSCS	Mg infusion mistaken for normal saline during re-exploration for bleeding after LSCS.
[30]	31/PET	Interhospital transfer	Antenatal	Confusion about measured magnesium plasma levels which affected the infusion rate.
[31]	Patient 1: PTL	Transfer	Postpartum (shortly after ND)	Soon after delivery, instead of oxytocin, rapid magnesium infusion. Vegetative state.
	Patient 2: PET	PP ward	Postpartum (12 h after ND)	The patient received two magnesium infusions simultaneously. Vegetative state.
	Patient 3: PET	Transfer	Antenatal	Inexperienced nurse increased the infusion rate from 2 g/h to 7 g/h during interhospital transfer
	Patient 4: PET	Labour ward	Antenatal	Inadequate handover led to increase in magnesium infusion rate (from 2 g/h to 4 g/h).
	Patient 5: PET	. Not reported	Antenatal	Verbal order and inadequate handover led to administration of two bolus doses.
	Patient 6: PET	Not reported	Antenatal	Misreading of labels led to admixture of 80 g then expected 40 g in 1 L bag.
	Patient 7: PTL	Not reported	Antenatal	Unlabelled infusion bag contained 40 g which was infused at 300 mL/h. Death.
	Patient 8: PTL	Not reported	Antenatal	Pump infusion rate not decreased after administration of bolus dose completion.
	Patient 9: PTL	Transfer (ED to Tertiary centre)	Antenatal	The nurse misinterpreted an order and added Mg in the premixed bag of normal saline with Mg.
	Patient 10: PET	Transfer (ED to PP ward)	Post-partum (4 days after ND)	Incorrect calculation of the magnesium infusion rate.

PET-preeclamptic toxaemia, PTL- preterm labour, LSCS- lower segment caesarean section, Mg-magnesium, g-gram, R/R-respiratory rate, ICU-intensive care unit, OR-operating room, ED-emergency department, LR- labour room, PP-postpartum, ND-normal delivery, PPH-postpartum haeomorrhage.

patients included imprecise and confusing labelling [28], lack of infusion pump resulting in 16 G administration within few minutes [22], 20 g loading dose in place of 4 g vial due to storage of 1 g and 5 g magnesium vial nearby [11], hospital's magnesium use and infusion policy violation during transfer from delivery suite to OR (infusion pump alone was removed from the IV line, allowing a free flow infusion) [20].

In nine postpartum women, the error occurrence timing was immediately, or a few hours or a few days after normal vaginal delivery [13,16,17,19,26,29,31].

All patients

Nearly two-thirds (63%, 29 out of 46) of patients developed either respiratory arrest (obstetrics 9 and non-obstetric 4) or cardiopulmonary arrest (10 obstetrics and 6 non-obstetrics). In cases of respiratory arrest only, management varied for obstetric patients, including oxygen therapy [18], bag-mask ventilation [15,17], or tracheal intubation [13,16,19,26]. All four non-obstetric patients with respiratory arrest only required tracheal intubation and mechanical ventilation [33,35,37] (Supplemental File 3 (Table)).

The permanent adverse outcomes were reported in the form of death (3 patients -2 obstetric and one non-obstetric) [12,31,36] and vegetative state (3 – 2 obstetric and one non-obstetric) [31,32].

Differential diagnosis (Table 1)

Wide-ranging clinical conditions were considered in the presence of acute iatrogenic hypermagnesemia (Table 1).

Human factors analysis and classification system data (Table 3)

The frequency of contributory factors for each subcategory of the four main categories of the HFACS is identified in the table (Table 3).

Of skill-based errors, the majority involved some attentional or memory failure, for example, failing to reduce the infusion rate once the bolus dose was completed. Perceptual errors were

Table 3
Contributory factors and their frequency for intravenous magnesium administration errors identified using the Human Factors Analysis and Classification System framework*. N1 and N2 frequency for obstetric (31 patients) and non-obstetric (15 patients) respectively.

	Sub-categories	Examples	N1	N2	Refs
Organizational 35 (27 + 8)	Climate	• Inconsistencies in Mg dosage recommendations • Inconsistencies in Mg level reporting (multiple reports) • Recurrent errors (multiple reports) • Lack of maternal transport facility	9	4	[12–16,17,24,27,30–32,34,36]
	Process	• Vials with different Mg concentrations/amount available (*e.g.*, 1 g, 4 g, 5 g, 8 g, 25 g) (multiple reports) • Procurement of look-alike ampoules, vials, infusion bags, pumps (multiple reports) • Interhospital or intrahospital transfer deficiencies (multiple reports) • The hospital pharmacy prepared identical Mg and oxytocin infusion bags	15	4	[11,14,19–21,23,26,27,31–34,38,40,42]
	Resources	• Education/training: Nursing, midwife • Inadequate staffing	3	–	[27,31]
Supervision 6	Inadequate	• Of untrained/inexperience staff	2	–	[27,30]
	Inappropriate planning	• Predominantly with regards to IV infusion set or for monitoring	4	–	[19,20,28,31]
Preconditions for unsafe acts 45 (32 + 13)	Tools/Technical	• Labelling issues (multiple reports) • Presence of look-alike ampoules/vials, infusion bags, pumps in clinical locations (multiple reports) • Intrahospital transfer of the patient without infusion pump from one clinical location to another (multiple reports) • Failure to use technical function of the infusion pump • Malfunction of total parental nutrition mixing device	11	2	[18,20,23,27,31–34,37]
	Physical environment	• Storage issues	3	1	[11,31,40]
	Mental state	• Attitude (*e.g.*, incorrect assumptions, complacency) (multiple reports) • Distraction, haste, • Multitasking	10	1	[20,23,26,27,29,31,41]
	Communication and coordination	• Verbal /written orders related to dose/prescription (multiple reports) • Inadequate handover/transition of care (multiple reports)	8	9	[21,24,25,31–33,35,38,39]
Unsafe acts 56 (40 + 16)	Skill-based	• Uncontrolled rapid administration (multiple reports): infusion set disconnected and not replaced, drip regulator incorrect manipulation, administration *via* burette instead of pump • Failure to reduce the infusion rate after loading dose • Incorrect calculation of infusion rate • Incorrect interpretation of prescription orders (multiple reports) • Magnesium administration in place of oxytocin or normal saline • Inexperienced staff did not operate infusion pump correctly • Inadequate mixing of Mgso4 in a plasmalyte solution	21	9	[12,13,15–17, 19,20,22–26,29,31,32,35,36,38–41]
	Perceptual	• Incorrect visual perception (multiple reports): *e.g.*, Mg ampoules/vials (4 g and 25 g, 4 g and 8 g), infusion bags (Mg and oxytocin, normal saline, 50% dextrose), pumps (*e.g.*, Mg and oxytocin)	7	2	[14,21,23,26,29,31,32,40]
	Decisions	• Failure or delayed inclusion of hypermagnesemia in differential diagnosis (multiple reports)	8	5	[11,23,25,28,29,31,33,35,37,39–41]
	Violations	• Failure to adhere to policy for patient transfer, storage, and monitoring	4	–	[19,20,27,31]

Mg-magnesium, g-gram. Refs-references.

Fig. 2. Availability of confusing magnesium products in varying concentrations and quantities in ampoules, vials and infusion bags.

predominantly due to incorrect visual perception of magnesium vials of different concentrations and confusion due to look-alike infusion bags or vials. Violations were mainly routine, *e.g.*, failure to adhere to local policies related to transfer or monitoring. Decision errors were due to confusion about the clinical features of hypermagnesemia in relation to other critical obstetric or non-obstetric medical conditions.

One or more of the preconditions for unsafe acts were evident in almost all reports, except for the physiological state of the provider. While communication issues were common for obstetric and non-obstetric errors, adverse mental states and technological problems were predominantly present in obstetric errors. Adverse mental state (refer to the mental conditions of clinical staff that may affect performance) included both cognitive states, such as work-related distraction, multitasking, and lack of awareness, as well as personality-related problems, such as attitude-related (*e.g.*, assumptions about infusions, lack of verifications during hand-over) and complacency related to changes in clinical symptoms and signs. Communication and coordination issues involved included substandard prescribing practices, deficiencies in inter- and intrahospital transfers, and inadequate verbal and written handovers (*e.g.*, incomplete information about magnesium administration) of clinical care.

The most common organisational factor was a process-related issue, typically arising from inadequate procurement procedures for purchasing vials with varying concentrations of magnesium, even within the same hospital, which often had similar labels. Organisational processes and policies for preparing IV magnesium infusions, as well as several clinical aspects (*e.g.*, inter- or intrahospital transfers of patients receiving IV magnesium infusions), were not standardized. Inadequate staff training to handle the infusion pump was evident in one incident.

Discussion

To the author's knowledge, the current study is the first systematic investigation of serious life-threatening risks associated with IV therapeutic use of magnesium in hospital settings, and aims to identify contributory factors applying the HFACS. Magnesium is available in multiple formulations, including 4%, 5%, 8%, 10%, 12.5%, 15%, 20% and 50% (Fig. 2). Furthermore, there are variable practices for preparing, dosing, and administering magnesium infusion [43]. Our investigation suggests that despite being considered a high-risk medication, recurrent problems existed at all HFACS levels, including skill-based errors, confusing magnesium products causing incorrect visual perception, inconsistent measurement units, substandard communication and transition of care practices, and poor organization processes and climate. In addition, the current investigation provides insight into the fact that errors can still occur, irrespective of the infusion device used, due to individual inaccurate assumptions, complacent attitudes, prescription-related issues, incorrect dilution, and a lack of technological knowledge about infusion devices. Many of these human and systemic factors are recurring and may persist. Multiple safeguards are necessary in working environments across the hospitals regarding the standardisation of concentrated magnesium sulphate products (*e.g.*, vials, ampules, infusion bags) and their availability for clinical use, infusion administration and discontinuation procedures, monitoring parameters (*e.g.*, sedation, respiratory, plasma levels) and intra or interhospital transition of patient care during therapeutic use of magnesium (Table 4).

During the preparation and administration of IV medication doses, the probability of making at least one error can be as high as 73% [44]. One multi-institutional observational study conducted in the USA and the UK revealed significant variability in practices and policies about IV infusion administration. It is a complex adaptive action involving humans (*e.g.*, providers and patients), technology (*e.g.*, hardware and software), and dynamic ward environments (*e.g.*, individual and team safety attitudes) within which it is carried out [45]. The evidence shows that infusion practices are not uniform among clinical areas; practical deviations are routine, and the availability and use of infusion devices are also inconsistent [4]. As a result, the error rate, contributory factors, consequences, and prevention strategies for

Table 4
Prevention of IV magnesium administration errors: Potential strategies and limitations.

Step	Potential prevention strategies	Potential barriers
Manufacturing	Standardisation of products and labels: Magnesium is available in multiple formulations, including 4%, 5%, 8%, 10%, 12.5%, 20% and 50%.	No regulation No incentive Lack of awareness
Organizational processes / Climate	Safer processes include the procurement of magnesium products and preparation and monitoring during magnesium therapy. Adequate staff to monitor patients receiving Mg infusion.	Accountability deficits Cost Lack of mechanisms to prevent recurrence
Labelling	Product labels standardisation to minimise confusion, *e.g.*, mg /mL, g/mL, %, w/v, total quantity (mg or g)/total volume (mL or L) (*e.g.*, in ampoule, or vial, or infusion bag)-Magnesium-specific, clear, high-alert / caution labels.	Lack of consensus and guidance for labelling Mg preparations Similarity with other labels
Storage	Prohibiting storage in clinical areas of higher than 4% undiluted formulation. Ergonomics to prevent selection errors.	Inadequate facility Availability of look-alike other products
Prescribing	Changing the practice of undiluted prescriptions to prescribing diluted doses of Mg. Electronic prescribing bundle for Mg	Required consensus among pharmacists, care providers
Preparation	Read labels before withdrawal from ampoules or vials Avoid preparation of infusion bags with large quantities of magnesium. Small volume (*e.g.*, 50–100 mL) commercial prediluted or pharmacy-prepared ready-to-use magnesium infusion syringes and bags. Separate magnesium solutions are used for bolus dose and maintaining infusion.	Lack of consensus and guidance Lack of double-check (human/barcode) Economic burden Confusing Mg products and labels
Pumps/devices for infusion	Prepare magnesium library protocol. Automated programming of Mg dose (*e.g.*, infusion rate) Advanced technological integration (*e.g.*, interfaced with barcode system and electronic health record). Preparation of Mg in a syringe and administration *via* a syringe driver. Audit Mg infusion pump-related safety practices.	Lack of availability Lack of technological knowledge (*e.g.*, safety features) Location-specific pumps Lack of compliance
Administration	Double-check error-prone prescription, preparation, dose calculation, infusion device, and connection to IV catheter. Identify IV and other route catheters and infusion pumps. Impalement magnesium therapeutic care bundle involving stakeholders, including dose regimens. Identify high-risk patients at risk for magnesium side effects. Check available measures to manage magnesium toxicity.	Cognition capability (*e.g.*, attention, memory) Incorrect assumptions Working environment (*e.g.*, distractions, multitasking) Violation of policy
Transfer	Standardise the transfer process for patients with magnesium infusion, *e.g.*, handling and monitoring infusions. Do not disconnect the infusion set from the pump until indicated to prevent accidental free flow.	Hurry Emergency surgery Not familiar with infusion-related details
Transition of care (Handover of care)	Standardise the handover process for patients with Mg infusion: Check all details, including preparation, labels, dose, infusion rate, intravenous connections, patient progress, monitoring, and documentation.	Workload (caring for multiple patients) Time pressures Distractions
Monitoring	Standardise units of measurement: Mg plasma levels are reported as mg/dL, mEq/L mmol/L, *etc.* Consider advanced respiratory monitoring in wards specifically for high-risk patients. Familiarise with Mg side effects and follow local guidance.	Complacency with changes in clinical condition No or insufficient tools for advanced monitoring
Reporting	Mechanisms to alert Mg-related incidents	No or inadequate system
Training / Education	Clinical features of magnesium toxicity. Simulation drills to improve team performance on Mg toxicity.	Temporary staff No resources

Mg-magnesium, mg-milligram, ml-millilitre, g-gram, L-litter, mmol-millimole, dl-decilitre.

IV infusion errors vary among clinical locations, from hospital to hospital and among medications [4].

Furthermore, hospital infrastructure and resources available to implement corrective measures may vary significantly. For example, advanced technological solutions and strategies to mitigate high-risk infusion medication errors, such as barcode-enabled administration, smart infusion pumps, and clinical decision support systems for safer magnesium administration in pregnant women, may be challenging to apply in resource-constrained circumstances (*e.g.*, rural areas) and less developed countries. The current investigation underscores the need to identify and improve deficiencies in individual clinical areas. It reveals alarming vulnerabilities to errors at every significant procedural step of magnesium use (*e.g.*, prescription, preparation, initiation of infusion, and transition from bolus to infusion). The findings may contribute to overcoming barriers to unsafe practices and formulating safer pathways to minimise magnesium administration-related incidents [46,47].

To date, limited studies have focused on medication errors and contributing human factors in pregnant women. Previous studies investigating medication errors in obstetrics have reported that 65-75% of errors occur during the administration stage [48,49]. When errors result in harm, they are mainly associated with the administration of IV oxytocin and magnesium [49]. One of the reports included in the current investigation provided details of harm in 10 patients due to accidental magnesium overdose administration [31]. However, the article did not evaluate systemic and human factors methodologically. Magnesium administration errors may occur *via* neuraxial routes in obstetric practice. Accidental magnesium administration *via* the intrathecal or epidural route has been reported to cause reversible paraplegia in pregnant women [50]. Some recent investigations suggest medication errors may involve other routine medications also, specifically in obstetric surgical patients (*e.g.*, during caesarean delivery). In one voluntary incident reporting study spanning 14 years, medication errors or issues involving oxytocin, anti-

biotics, vasopressors, and opioids formed 29% of 469 incidents reported during caesarean delivery [51]. In recent times, inadvertent intrathecal administration of tranexamic acid and digoxin during spinal anaesthesia for caesarean section resulted in devastating consequences, including death and permanent paraplegia [52,53].

Our study contrasts with the recent findings of Alves *et al.*'s systematic review on harm prevalence due to medication errors involving high-alert medications, in which the authors did not find evidence that magnesium is associated with a high probability of harm when used in error [54]. In the current study, due to rapid IV magnesium administration, severe adverse outcomes occurred in the form of respiratory arrest only and cardiopulmonary arrest in 61.2% of obstetric and 66.6% of non-obstetric patients. There may be a publication bias because magnesium administration incidents result in fewer harmful effects, or near-miss situations may not get published.

One major contributing factor was the underutilisation of infusion pumps, resulting in inadvertent rapid and extensive dose administration or unsafe handling of infusion devices (*e.g.*, infusion sets, pumps). Magnesium infusion administration typically requires the use of an infusion pump in modern clinical practice. However, it is noteworthy that some errors occurred following the removal of the infusion set from the pump after the termination of magnesium therapy or during the transfer from one clinical location to another. If a specific infusion device is available, the user should be familiar with the infusion pump's safety features, including drug library programming functions [55]. In addition, a standardised magnesium library protocol, automated programming, advanced technological integration (*e.g.*, infusion pump interfaced with a barcode system and electronic health record), monitoring of compliance, and staff training may improve administration safety during the use of advanced infusion pumps [56].

Our study highlights the recurrent, inherent risk of dilution and preparation practices involving large quantities of magnesium in infusion bags. The preparation and dose calculation for magnesium sulphate infusions may also be prone to errors due to the expression of concentration as %w/v, mmol/mL, mg/mL, and g/mL on ampoules or vials of concentrated magnesium sulphate solutions (Fig. 2). A standardised system governing the preparation and dilution of medications, as well as the containers (*e.g.*, syringe size and solvent volume), must be formally established within the hospital or clinical areas to ensure uniform practice at a given site [57]. A description of the established protocol must be available in the working areas [57]. Small-volume pre-mixed pharmacies, commercially prepared syringes, or infusion bags that meet the clinical needs of patients are also options to minimise human errors. Prefilled syringes may be a better option, as magnesium infusion bags can lead to incorrect visual perception with other infusion bags containing medications such as oxytocin, local anaesthetics, and antibiotics. Prefilled syringes eliminate several preparations and other steps susceptible to errors, including labelling [58]. The hospital pharmacy can limit magnesium supply to only lower strengths, facilitate computerised prescribing orders, and provide staff education, such as double-checking. However, further work is required to reach a consensus and achieve consistency regarding magnesium product labels, plasma levels reporting, and the impact of specific prevention measures on reducing magnesium-related medication errors.

There is limited information on medication errors associated with maternal transfer from one location to another or related to the handover of care from one healthcare provider to another. One-third of errors in the current study were associated with patient transfer. Poor communication habits among healthcare providers, incomplete information about ongoing infusions, and inadequate checks, including those of infusion devices upon arrival in new clinical care areas, were common contributing factors. Other communication challenges among maternal care professionals included issues with prescription and documentation. The findings support the conclusions of previous studies that insufficient handling of infusions during patient transfer, inadequate exchange of information, and incomplete handover practices are associated with adverse outcomes, including medication errors [59,60].

Undetected severe respiratory depression due to magnesium toxicity may lead to hypoxia, hypercarbia, cardiac dysrhythmias, and eventually cardiac arrest. The current study presents an opportunity to enhance cardiorespiratory monitoring of patients, particularly those in high-risk obstetric care who receive magnesium infusions. The scenario is somewhat like opioid-induced respiratory depression-related morbidity and mortality. In one adult population study over 6 years, four deaths occurred in 32 patients who experienced postoperative critical respiratory events [61]. In another study of 10 years, the rescue system with continuous surveillance monitoring had a profound effect on death from sedative/analgesic administration in the general care settings [62]. Continuous respiratory monitoring of respiratory physiology parameters, including oxygen saturation *(e.g.*, pulse oximetry), end-tidal CO_2 (*e.g.*, capnography), and respiratory rate (*e.g.*, with technology such as thoracic impedance, acoustic plethysmography, and photoplethysmography), may prevent morbidity and mortality in high-risk patients receiving magnesium infusions [63]. Further research is needed to investigate the clinical challenges associated with advanced monitoring in obstetric patients during magnesium infusion, as well as the economic aspects of its implementation.

Limitations

The study cannot determine the actual incidence rate of IV magnesium errors due to a lack of a denominator. There is a publication bias and a lack of generalizability in the analysis of case reports. The current review might have overestimated the clinical risks associated with the therapeutic use of magnesium. There may be unreported and unpublished near misses involving IV magnesium administration. We have inferred some human and systemic contributory factors from the reports. The harm analysis focused on severe harm and serious outcomes such as respiratory or cardiopulmonary arrest, vegetative state, and death. Some reports' details were incomplete (*e.g.*, infusion devices, educational and training aspects, and monitoring facilities). Many reports did not provide details of neonatal outcomes or follow-up following delivery. Magnesium crosses the placenta, and the foetus cannot metabolise magnesium. Magnesium toxicity has impacted neonatal outcomes in some women. We also could not explore any correlation between serum magnesium levels and clinical consequences or recovery because the administered dose was variable, and the timing of plasma level measurements was also inconsistent.

Conclusions

Intravenous magnesium administration errors occurred in multiple locations, including obstetric, medical, and surgical wards and acute care settings. Multiple administration steps are vulnerable, including preparing the magnesium dose, changing from loading to maintenance infusion, and cardiorespiratory monitoring during IV use. The plethora of magnesium commercial preparations in varying concentrations and their differing strengths, as expressed on product labels, is confusing. The HFACS demonstrated the existence of deficiencies at all levels, including

skill-based errors in magnesium infusion preparation and administration, substandard practices during the transition of care or transfer of patients, and inadequate organisational processes and climate. Nearly two-thirds of patients developed respiratory arrest or cardiopulmonary arrest during loading or maintenance infusion administration incidents, resulting in adverse outcomes. Applying advanced technological monitoring for early detection of respiratory depression and management may minimise irreversible adverse outcomes. Further international research is required on magnesium administration practices and monitoring during therapeutic use to enhance patient safety.

CRediT authorship contribution statement

All authors attest that they meet the current International Committee of Medical Journal Editors (ICMJE) criteria for Authorship.

Funding

The authors have no sources of funding to declare for this manuscript

Declaration of competing interest

The authors declare that they have no known competing financial or personal relationships that could be viewed as influencing the work reported in this paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.accpm.2025.101621.

References

[1] Härkänen M, Vehviläinen-Julkunen K, Murrells T, Rafferty AM, Franklin BD. Medication administration errors and mortality: incidents reported in England and Wales between 2007 – 2016. Res Soc Adm Pharm 2019;15:858–63. http://dx.doi.org/10.1016/j.sapharm.2018.11.010.
[2] Mendes JR, Lopes MC, Vancini-Campanharo CR, Okuno MF, Batista REA. Types and frequency of errors in the preparation and administration of drugs. Einstein (São Paulo) 2018;16eAO4146. http://dx.doi.org/10.1590/S1679-45082018AO4146.
[3] Keers RN, Williams SD, Cooke J, Ashcroft DM. Causes of medication administration errors in hospitals: a systematic review of quantitative and qualitative evidence. Drug Saf 2013;36:1045–67. http://dx.doi.org/10.1007/s40264-013-0090-2.
[4] Lyons I, Furniss D, Blandford A, Chumbley G, Iacovides I, Wei L, et al. Errors and discrepancies in the administration of intravenous infusions: a mixed methods multihospital observational study. BMJ Qual Saf 2018;27:892–901. http://dx.doi.org/10.1136/bmjqs-2017-007476.
[5] ISMP List of High-Alert Medications in Acute Care Settings. ISMP_HighAlert_AcuteCare_List_010924_MS5760.pdf. https://home.ecri.org/blogs/ismp-resources/high-alert-medications-in-acute-care-settings [Accessed 15th March 2025].
[6] Brookfield KF, Mbata O. Magnesium sulfate use in pregnancy for preeclampsia prophylaxis and fetal neuroprotection: regimens in high-income and low/middle-income countries. Obstet Gyn Clin North Am 2023;50:89–99. http://dx.doi.org/10.1016/j.ogc.2022.10.003.
[7] Mercer BM, Merlino AA. Society for maternal-fetal medicine. Magnesium sulfate for preterm labor and preterm birth. Obstet Gynecol 2009;114:650–68. http://dx.doi.org/10.1097/AOG.0b013e3181b48336.
[8] Ambrożej D, Adamiec A, Forno E, Orzołek I, Feleszko W, Castro-Rodriguez JA. Intravenous magnesium sulfate for asthma exacerbations in children: systematic review with meta-analysis. Paediatr Respir Rev 2024;52:22–30. http://dx.doi.org/10.1016/j.prrv.2024.01.003.
[9] Mathew AA, Panonnummal R. 'Magnesium'-the master cation-as a drug—possibilities and evidences. Biometals 2021;34:955–86. http://dx.doi.org/10.1007/s10534-021-00328-7.
[10] Choi GJ, Kim YI, Koo YH, Oh HC, Kang H. Perioperative magnesium for postoperative analgesia: an umbrella review of systematic reviews and updated meta-analysis of randomized controlled trials. J Pers Med 2021;11:1273. http://dx.doi.org/10.3390/jpm11121273.
[11] McCubbin JM, Sibai BM, Ardella TN. Cardiopulmonary arrest due to acute maternal hypermagnesaemia. Lancet 1981;1(8228):1058. http://dx.doi.org/10.1016/s0140-6736(81)92225-x.
[12] Richards A, Stather-Dunn L, Moodley J. Cardiopulmonary arrest after the administration of magnesium sulphate. A case report. S Afr Med J 1985;67:145. PMID: 3969602.
[13] Bohman VR, Cotton DB. Supralethal magnesemia with patient survival. Obstet Gynecol 1990;76:984–6. PMID: 2120648.
[14] Swartjes JM, Schutte MF, Bleker OP. Management of eclampsia: cardiopulmonary arrest resulting from magnesium sulphate overdose. Eur J Obstet Gynaecol Reprod Biol 1992;47:73–5. http://dx.doi.org/10.1016/0028-2243(92)90217-m.
[15] Brühwiler H, Häfliger M, Lüscher KP. Severe accidental magnesium poisoning in a twins pregnancy in the 32nd week of pregnancy. Geburtshilfe und Frauenheilkunde 1994;54:184–6. http://dx.doi.org/10.1055/s-2007-1023579.
[16] Rabinerson D, Gruber A, Kaplan B, Royburt M, Ovadia J. Accidental cardiopulmonary arrest following magnesium sulphate overdose. Eur J Obstet Gynaecol Reprod Biol 1994;55:149–50. http://dx.doi.org/10.1016/0028-2243(94)90071-x.
[17] Wax JR, Segna RA, Vandersloot JA. Magnesium toxicity and resuscitation—an unusual cause of postcesarean evisceration [letter]. Int J Gynecol Obstet 1995;48:213–4. http://dx.doi.org/10.1016/0020-7292(94)02251-s.
[18] Cao Z, Bideau R, Valdes Jr R, Elin RJ. Acute hypermagnesemia and respiratory arrest following infusion of MgSO4 for tocolysis. Clin chimica acta 1999;285:191–293. http://dx.doi.org/10.1016/s0009-8981(99)00110-2.
[19] Fletcher SJ, Parr MJ. Life-threatening magnesium toxicity. Intensive Care Med 2000;26:257. http://dx.doi.org/10.1007/s001340050063.
[20] Morisaki H, Yamamoto S, Morita Y, Kotake Y, Ochiai R, Takeda J. Hypermagnesemia induced cardiopulmonary arrest before induction of anaesthesia for emergency caesarean section. J Clin Anesth 2000;12:224–6. http://dx.doi.org/10.1016/s0952-8180(00)00142-2.
[21] Kim TK, Kim YS, Yoon JR, Han IS, Moon HS, Kim JS. Accidental intravenous administration of magnesium sulfate during cesarean section: a case report. Kor J Anesthesiol 2003;45:656–60. http://dx.doi.org/10.4097/kjae.2003.45.5.656.
[22] McDonnell NJ. Cardiopulmonary arrest in pregnancy: two case reports of successful outcomes in association with perimortem Caesarean delivery. Br J Anaesth 2009;103:406–9. http://dx.doi.org/10.1093/bja/aep176.
[23] McDonnell NJ, Muchatuta NA, Paech MJ. Acute magnesium toxicity in an obstetric patient undergoing general anaesthesia for caesarean delivery. Int J Obstet Anesth 2010;19:226–31. http://dx.doi.org/10.1016/j.ijoa.2009.09.009.
[24] Buettner AU. Two cases of inadvertent magnesium sulphate overdose. Int J Obstet Anesth 2011;20:92–3. http://dx.doi.org/10.1016/j.ijoa.2010.08.003.
[25] Feng S, Huang W, Luo D, Lin X. Delayed recovery from general anaesthesia in a parturient with magnesium toxicity and acidosis. Anaesth Intensive Care 2013;41:125–7. PMID: 23362909.
[26] Kumar K, Al Arebi A, Singh I. Accidental intravenous infusion of a large dose of magnesium sulphate during labor: a case report. J Anaesthesiol Clin Pharmacol 2013;29:377–9. http://dx.doi.org/10.4103/0970-9185.117105.
[27] Grissinger M. Avoiding patient harm from a mmagnesium bolus dose. Pharm Ther 2014;39:81. PMID: 24669174; PMCID: PMC3956395.
[28] Wex F, Luze R, Franke J, Ramoni A, Gizewski E, Lucovnik M, et al. Magnesium sulfate overdose resulting in maternal cardiac arrest: a case report. Clin Obstet Gynecol Reprod Med 2020;6:1–4. http://dx.doi.org/10.15761/COGRM.1000316.
[29] Friedman-Korn T, Lerner Y, Haggiag S, Nama A, Ekstein D, Argov Z, et al. Pearls and Oysters: reversible postpartum pseudo-coma state associated with magnesium therapy: a report of 2 cases. Neurology 2022;99:433–6. http://dx.doi.org/10.1212/WNL.0000000000200956.
[30] Omer MS, Latif S, Grisson R. Iatrogenic Hypermagnesemia in a patient with preeclampsia caused by misinterpretation of the magnesium reporting unit following magnesium sulfate administration. Cureus 2022;14e32446. http://dx.doi.org/10.7759/cureus.32446.
[31] Simpson KR, Knox GE. Obstetrical accidents involving intravenous magnesium sulphate. Recommendations to promote patient safety. Am J Matern Child Nurs 2004;29:161–71. http://dx.doi.org/10.1097/00005721-200405000-00006.
[32] Hoffman RS, Smilkstein MJ, Rubenstein F. An "amp" by any other name: the hazards of intravenous magnesium dosing. JAMA 1989;261:557. http://dx.doi.org/10.1001/jama.1989.03420040091020.
[33] Rizzo MA, Fisher M, Lock JP. Hypermagnesemic pseudocoma. Arch Intern Med 1993;153:1130–2. http://dx.doi.org/10.1001/archinte.1993.00410090072009.
[34] Kuiper JJ. Communicating magnesium content. Arch Intern Med 1994;154:922–3. http://dx.doi.org/10.1001/archinte.1994.00420080132014.
[35] Frohna WJ. Iatrogenic magnesium overdose in a patient with suspected acute myocardial infarction. Am J Emerg Med 1995;13:436–7. http://dx.doi.org/10.1016/0735-6757(95)90134-5.
[36] Vissers RJ, Purssell R. Iatrogenic magnesium overdose: two case reports. J Emerg Med 1996;14:187–91. http://dx.doi.org/10.1016/0736-4679(95)02115-9.
[37] Ali A, Walentik C, Mantych GJ, Sadiq HF, Keenan WJ, Noguchi A. Iatrogenic acute hypermagnesemia after total parenteral nutrition infusion mimicking septic shock syndrome: two case reports. Pediatrics 2003;112:e70–2. http://dx.doi.org/10.1542/peds.112.1.e70.

[38] Despande GG, Gharpure V, Sarnaik AP, Valentini RP. Acute hypermagnesemia in a child. Ame J Health Syst Pharm 2006;63:262–5. http://dx.doi.org/10.2146/ajhp050319.
[39] Groselj-Grenc Mojca, Grosek Stefan, Grenc Damjan. Iatrogenic magnesium poisoning in 8-week old infant with implanted permanent pacemaker. Cli Toxicol 2012;50:331. http://dx.doi.org/10.1007/s40278-014-1259-x.
[40] Cohen M. Medication errors. Nursing 2014;44:72. http://dx.doi.org/10.1097/01.NURSE.0000450799.33720.72.
[41] Cavell GF, Bryant C, Jheeta S. Iatrogenic magnesium toxicity following intravenous infusion of magnesium sulfate: risks and strategies for prevention. BMJ Case Rep 2015. http://dx.doi.org/10.1136/bcr-2015-209499. bcr2015209499.
[42] Ghavidel A. What happens when a large dose of magnesium sulfate is infused intravenously? J Anal Res Clin Med 2016;4:129–32. http://dx.doi.org/10.15171/jarcm.2016.021.
[43] Long Q, Oladapo OT, Leathersich S, Vogel JP, Carroli G, Lumbiganon P, et al. WHO multicountry survey on maternal and newborn health research network. Clinical practice patterns on the use of magnesium sulphate for treatment of pre-eclampsia and eclampsia: a multi-country survey. Brit J Obst Gyn 2017;124:1883–90. http://dx.doi.org/10.1111/1471-0528.14400.
[44] McDowell SE, Mt-Isa S, Ashby D, Ferner RE. Where errors occur in the preparation and administration of intravenous medicines: a systematic review and Bayesian analysis. Qual Saf Health Care 2010;19:341–5. http://dx.doi.org/10.1136/qshc.2008.029785.
[45] Blandford A, Dykes PC, Franklin BD, Furniss D, Galal-Edeen G, Schnock K, et al. Intravenous infusion administration: a comparative study of practices and errors between the United States and England and their Implications for patient safety. Drug Saf 2019;42:1157–65. http://dx.doi.org/10.1007/s40264-019-00841-2.
[46] Wolf ZR, Hughes RG. Best practices to decrease infusion-associated medication errors. J Infus Nurs 2019;42:183–92. http://dx.doi.org/10.1097/NAN.0000000000000329.
[47] Park J, You SB, Ryu GW, Kim Y. Attributes of errors, facilitators, and barriers related to rate control of IV medications: a scoping review. Syst Rev 2023;12:230. http://dx.doi.org/10.1186/s13643-023-02386-z.
[48] Beyea SC, Kobokovich LJ, Becker SC, Hicks RW. Medication errors in the LDRP. AWHONN Lifelines 2004;8:130–40. http://dx.doi.org/10.1177/1091592304265564.
[49] Kfuri TA, Morlock L, Hicks RW, Shore A. Medication errors in obstetrics. Clin Perinatol 2008;35:101–17. http://dx.doi.org/10.1016/j.clp.2007.11.015.
[50] Patel S. Epidural and intrathecal magnesium sulphate administration errors: clinical features and contributing factors. Br J Anaesth 2023;130:e435–40. http://dx.doi.org/10.1016/j.bja.2022.12.015.
[51] Eley VA, Culwick MD, Dennis AT. Analysis of anaesthesia incidents during caesarean section reported to webAIRS between 2009 and 2022. Anaesth Intensive Care 2023;51:391–9. http://dx.doi.org/10.1177/0310057X231196915.
[52] Patel S. Tranexamic acid-associated intrathecal toxicity during spinal anaesthesia: a narrative review of 22 recent reports. Eur J Anaesthesiol 2023;40:334–42. http://dx.doi.org/10.1097/EJA.0000000000001812.
[53] Patel S. Cardiovascular drug administration errors during neuraxial anesthesia or analgesia—a narrative review. J Cardiothorac Vasc Anesth 2023;37:291–8. http://dx.doi.org/10.1053/j.jvca.2022.10.016.
[54] Sodré-Alves B, Andrade T, Santos S, Junior D, Filho D. Harm prevalence due to medication errors involving high-alert medications: a systematic review. J Pat Saf 2021;17:e1–9. http://dx.doi.org/10.1097/PTS.0000000000000649.
[55] Kirkendall ES, Timmons K, Huth H, Walsh K, Melton K. Human-based errors involving smart infusion pumps: a catalog of error types and prevention strategies. Drug Saf 2020;43:1073–87. http://dx.doi.org/10.1007/s40264-020-00986-5.
[56] Giuliano KK, Mahuren RS, Balyeat J. Data-based program management of system-wide IV smart pump integration. Am J Health Syst Pharm 2024;81:e30–6. http://dx.doi.org/10.1093/ajhp/zxad245.
[57] Risk Management Analysis Committee of the French Society for Anesthesia and Critical Care (SFAR). French Society for Clinical Pharmacy (SFPC). Preventing medication errors in anesthesia and critical care (abbreviated version). Anaesth Crit Care Pain Med 2017;36:253–8. http://dx.doi.org/10.1016/j.accpm.2017.04.002.
[58] Whitaker DK, Lomas JP. Time for prefilled syringes - everywhere. Anaesthesia 2024;79:119–22. http://dx.doi.org/10.1111/anae.16181.
[59] Bristol AA, Schneider CE, Lin SY, Brody AA. A systematic review of clinical outcomes associated with intrahospital transitions. J Healthc Qual 2020;42:175–87. http://dx.doi.org/10.1097/JHQ.0000000000000232.
[60] Bourne RS, Jeffries M, Phipps DL, Jennings G, Boxall E, Wilson F, et al. Understanding medication safety involving patient transfer from intensive care to hospital ward: a qualitative sociotechnical factor study. BMJ Open 2023;13e066757. http://dx.doi.org/10.1136/bmjopen-2022-066757.
[61] Ramachandran SK, Haider N, Saran KA, et al. Life-threatening critical respiratory events: a retrospective study of postoperative patients found unresponsive during analgesic therapy. J Clin Anesth 2011;23:207–13. http://dx.doi.org/10.1016/j.jclinane.2010.09.003.
[62] McGrath SP, McGovern KM, Perreard IM, Haung V, Moss L, Bilke G. Inpatient respiratory arrest associated with sedative and analgesic medications: impact of continuous monitoring on patient mortality and severe morbidity. J Pat Saf 2021;17:557–61. http://dx.doi.org/10.1097/PTS.0000000000000696.
[63] Bauchat JR, Weiniger CF, Sultan P, Habib A, Ando K, Kowalczyk. et al. Society for obstetric anesthesia and perinatology consensus statement: monitoring recommendations for prevention and detection of respiratory depression associated with administration of neuraxial morphine for cesarean delivery analgesia. Anesth Analg 2019;129:458–74. http://dx.doi.org/10.1213/ANE.0000000000004195.